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(54) Title: METHOD FOR DERIVING NOISE-REDUCED ESTIMATES OF COLOUR SIGNAL PARAMETERS FROM MULTIPLE COLOUR/LUMINANCE IMAGE SENSOR OUTPUTS
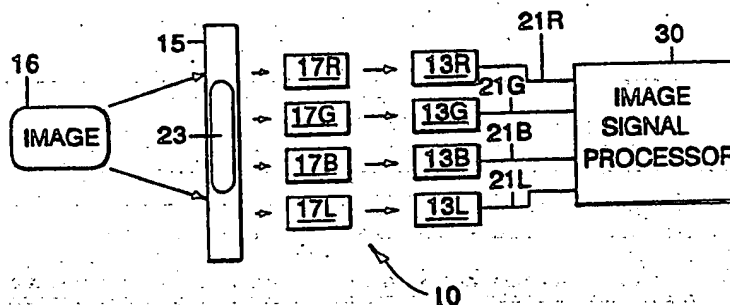
(57) Abstract

Color and luminance measurement signals produced by the multiple sensors of a multiband (e.g. RGB color) image signal processing system are processed to reduce noise. For images such as those obtained from a multi-dye film, the luminance component of the output signal from the luminance sensor may be expressed as a function of the color components of the color sensor output signals. A first signal, representative of the constructed low frequency luminance signal, is produced as a linear function of the color sensor output signals, employing signal weighting coefficients derivable from intrinsic characteristics of the scanned image, such as the respective dye densities of a three layer color film. The luminance measurement signal derived from the luminance sensor is subtracted from this first signal, to produce a second signal, which is multiplied by a set of respective scaling factors, which are then subtracted from each color sensor output, so as to derive a set of noise-reduced estimates of the color components of each of the color sensor output signals. Each scaling factor is defined in accordance with the noise variances associated with the operation of the color image sensors and the luminance image sensor, and is proportional to a product of a corresponding one of the coefficients and the ratio of the noise variance associated with the operation of a respective color image sensor to a summation of the noise variances associated with the operation of each of the color sensors and the luminance sensor.

METHOD FOR DERIVING NOISE-REDUCED ESTIMATES OF COLOUR SIGNAL PARAMETERS

FROM MULTIPLE COLOUR/LUMINANCE IMAGE SENSOR OUTPUTS

5   FIELD OF THE INVENTION

The present invention relates in general to color imagery signal processing and is particularly directed to a mechanism for deriving noise-reduced color signal estimates from a multiple sensor color

10   imaging system.

BACKGROUND OF THE INVENTION

Multi-channel signal processing systems often contain a larger number of sensors than there are bands

15   of information to be extracted. Namely, they may be characterized as containing n sensors for deriving m bands of information, where $n>m$. For example, a color imagery sensing system, such as employed for high definition television, may, on occasion, contain four

20   image sensors, three of which provide relatively low spatial resolution measurements of the red, green and blue components of an image, such as the red (R), green (G) and blue (B) density of a color film, while the fourth sensor provides a relatively high spatial

25   resolution, luminance-representative (L) output signal. A low spatial frequency luminance signal is generated by resampling the original high resolution luminance signal, so as to replicate the resolution at which the red, green and blue signals are measured. Subtracting

30   this low frequency luminance from the original luminance signal yields only its high frequency component. (Aside from this subtraction step, the low frequency luminance information is not used.) The resulting high frequency component is then added to the

35   red, green and blue signals to produce high frequency information for these channels.

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Due to the imperfect nature of the sensors,
each output signal inherently possesses some degree of
sensor-induced noise, so that the output may be
expressed as the sum of an intended parameter p_i, plus
5   a noise component n_{pi} associated with the sensor's
measurement of that parameter. Consequently, reducing
the magnitude of this noise component would enable the
system to provide a more faithful reconstruction of its
input image. Fortunately, since a typical film strip
10   contains only three dyes, the system is essentially
measuring the values of three parameters (dye
densities) on the basis of four measurements (red,
green blue and luminance transmittances). Moreover,
even when the system is making measurements on a scene
15   which contains a full spectrum of colors (e.g. the real
world), because the spectral sensitivity of the
luminance sensor usually overlaps that of the other
sensors (e.g. RGB color sensors), the (low frequency)
luminance component will contain information that is
20   related to the parameter measurements in the color
sensor outputs.

SUMMARY OF THE INVENTION

In accordance with the present invention,
25   advantage is taken of this additional source of
information in the low frequency luminance signals, so
as to reduce the noise in the color signals output by
the color sensors. More particularly, the present
invention is directed to a multiband (e.g. R,G,B,L)
30   image signal processing system having a plurality of
color image sensors, each of which produces a
respective color output signal that contains a
respective color representative component of the image
and a noise component associated with the operation of
35   the color sensor through which its output signal is
produced. For images such as those obtained from the

above-referenced three layer film, the luminance
component of the output signal from the luminance
sensor may be expressed as a function of the color
components of the color sensor output signals. Namely,

5   the luminance sensor output L may be expressed as the
sum of a function $f(r,g,b)$ and the luminance sensor
noise n_L, where r, g and b are the color components
within the color sensor outputs for which reduced-noise
estimates are desired.

10   The signal processing mechanism according to
the present invention processes a vector c_i of inputs
(intrinsic parameters) and a vector c_0 of measurable
outputs, related by a function $\vec{c}_0 = F(\vec{c}_1)$ which may, in
some cases, be approximated by a matrix $\vec{c}_0 = A\vec{c}_1$. For

15 a four sensor color imagery processing system, sensor
outputs are processed to reduce the noise components in
the color sensor output signals and thereby derives
noise-reduced estimates of each of the color components
within these sensor output signals. To this end, a

20 first signal, S1, which is representative of the low
frequency luminance signal, is produced as a linear
function of the color sensor output signals, in the
form S1 = (AR + BG + CB), where A, B and C are signal
weighting coefficients derivable from intrinsic

25 characteristics of the scanned image, such as the
respective dye densities of a three layer color film.
The luminance measurement signal derived from the
luminance sensor is subtracted from this first signal
S1, to produce a second signal S2. This second signal

30 S2 is then multiplied by a set of respective scaling
factors, which are then subtracted from each color
sensor output, so as to derive a set of noise-reduced
estimates of the color components of each of the color
sensor output signals. Each scaling factor is defined

35 in accordance with the noise variances associated with
the operation of the color image sensors and the

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luminance image sensor, and is proportional to a
product of a corresponding one of the coefficients A, B
and C, and the ratio of the noise variance associated
with the operation of a respective color image sensor
5   to a summation of the noise variances associated with
the operation of each of the color sensors and the
luminance sensor.

BRIEF DESCRIPTION OF THE DRAWINGS
10   The single Figure diagrammatically shows a
color image processing system employing multiple image
sensors and a dedicated color signal processor.

DETAILED DESCRIPTION
15   Before describing the details of an
embodiment of the present invention, it should be
observed that the invention resides primarily in a
novel color signal noise reduction mechanism, rather
than a particular implementation of that mechanism.
20 Moreover, although, in its preferred embodiment, the
invention is implemented using a programmed digital
computer, the noise reduction mechanism may be carried
out by means of a variety of structural combinations of
conventional signal processing circuits and components,
25 such as custom-configured integrated circuit hardware.
Accordingly, the structure, control and arrangement of
the signal processing hardware of an embodiment of the
invention have been illustrated in the drawings by a
readily understandable block diagram, which shows only
30 those specific details that are pertinent to the
present invention, so as not to obscure the disclosure
with structural details which will be readily apparent
to those skilled in the art having the benefit of the
present description.
35   Figure 1 illustrates an exemplary application
of the present invention to a signal processing

environment that employs a first plurality of n
measurements on a second plurality of m intrinsic
variables. Specifically, for purposes of the present
description, the environment is that of a multi-color
5   image processing system which carries out n=4
measurements on m=3 intrinsic variables and comprises a
(multiple sensor) color image section 10, containing
red, green, blue and luminance sensitive sensors 13R,
13G, 13B and 13L arranged on one side of a three layer
10   color film strip 15, that is illuminated by light
source 16 having a spectral light intensity $I(\lambda)$.
Situated in front of the sensors are respective input
filters 17R, 17G, 17B and 17L, having respective
transmittances $T_r(\lambda)$, $T_g(\lambda)$, $T_b(\lambda)$ and $T_L(\lambda)$. Each
15   sensor produces image characteristic-representative
digital signals, i.e. respective red, green, blue and
luminance channel signal values representative of the
red, green, blue and luminance components of a color
image 23 captured on film strip 15 which are coupled
20   over links 21R, 21G, 21B and 21L to a processor 30.

        As pointed out above, in the course of
operation of such a multi-channel (e.g. three color
band, luminance band) image scanning system, the color
channel sensors 13R, 13G, 13B provide relatively low
25   spatial resolution measurements of respective red R,
green G and blue B components of the film, such as its
red, green and blue densities, while the fourth,
luminance, sensor 13L provides a relatively high
spatial resolution luminance representative output
30   signal. A low spatial frequency luminance signal is
generated by resampling the original high resolution
luminance signal, so as to replicate the resolution at
which the red, green and blue signals are measured.
Subtracting this low frequency luminance from the
35   original luminance signal yields only its high
frequency component. The resulting high frequency

component is then added to the red, green and blue
signals to produce high frequency information for these
channels.

When film strip 15 is scanned by system 10,
5   the output signals produced by the respective color and
luminance sensors 13R, 13G, 13B and 13L contain noise
components that are associated with the operation of
the sensors themselves. Namely, these noise components
are effectively independent of the image and therefore
10   constitute signal processing anomalies that prevent a
true reconstruction of whatever comprises the original
image as seen by the imaging system. The object of the
present invention is to correct or reduce these
inserted errors; it does not serve to correct flaws in
15   the original image (within film strip 15).

In terms of signal definitions, each color
sensor output may be expressed as the sum of an
intended parameter p_i, plus a noise component n_{pi}
associated with the sensor's measurement of that
20   parameter. Consequently, reducing the magnitude of
this noise component will enable the system to provide
a more faithful reconstruction of its input image.
Fortunately, since film strip 15 typically contains
only three dyes, the system is essentially measuring
25   the values of three parameters (dye densities) on the
basis of four measurements (red, green, blue and
luminance transmittances). Moreover, the (low
frequency) luminance component L contains information
that is related to the parameter measurements in the
30   color sensor outputs.

As noted above, pursuant to the present
invention, advantage is taken of this additional source
of information in the low frequency luminance signals,
to reduce the noise in the color measurement signals R,
35   G and B output by color sensors 13R, 13G and 13R. In
order to facilitate an understanding of the signal

processing mechanism of the present invention, it is useful to initially define the signal outputs of each of sensors 13 of scanning system 10. Specifically, for an arbitrary pixel within each sensor, R, G and B

5 denote the signals measured by the red, green and blue sensors 13R, 13G and 13B, respectively, and L denotes the low frequency luminance signal (for the same pixel location) for the measured luminance signal. The signal values R, G, B and L may be defined as:

10

$$R = r+n_r, \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)$$
$$G = g+n_g, \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$
$$B = b+n_b, \text{ and } \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3)$$
$$L = f(r,g,b)+n_L \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

15

(Note that this model set of definitions is appropriate for scanning a three-layer film,, but not for looking at real-world scenes.) Here each noise value n_i is an independent observation noise which is normally

20 distributed with zero mean and variance σ^2_i (σ^2_L is the effective noise variance of the noise in the low-frequency luminance signal). The r, g, and b parameters are the "true" or noise-free red, green and blue transmittances. The function f is the

25 (deterministic) relationship between the red, green and blue transmittances and the (low-frequency) luminance transmittance. An implicit expression for the function f may be obtained by considering the details of the scanning process.

30 The scanner uses a light source 16 (with spectral intensity $I(\lambda)$ shining through film 15 containing three color layers with dye densities d_1, d_2 and d_3. The optical densities of these dyes, as a function of wavelength, are $D_1(\lambda)$, $D_2(\lambda)$ and $D_3(\lambda)$.

35 Finally, sensors 13R, 13G, 13B and 13L look at the

transmitted light through respective filters 17R, 17G, 17B and 17L with transmittances $T_r(\lambda)$, $T_g(\lambda)$, $T_b(\lambda)$ and $T_L(\lambda)$. If sensors 13R, 13G, 13B and 13L produced noise-free output signals, the respective light intensities that would be measured are:

$$r = \int I(\lambda) 10^{-\Sigma_i d_i D_i(\lambda)} T_r(\lambda) d\lambda, \quad \ldots \ldots \ldots (5)$$

$$g = \int I(\lambda) 10^{-\Sigma_i d_i D_i(\lambda)} T_g(\lambda) d\lambda, \quad \ldots \ldots \ldots (6)$$

$$b = \int I(\lambda) 10^{-\Sigma_i d_i D_i(\lambda)} T_b(\lambda) d\lambda, \text{ and } \ldots \ldots (7)$$

$$f(r,g,b) = \int I(\lambda) 10^{-\Sigma_i d_i D_i(\lambda)} T_L(\lambda) d\lambda, \quad \ldots \ldots (8)$$

The dye densities d_i of film 15 are derived by solving the equations (5), (6) and (7) and then are used in equation (8) to determine the value of f. For general spectral characteristics, this non-linear equation (8) is the simplest expression for f. However, if the effective filter for the luminance channel is a linear combination of the effective filters for the red, green and blue channels, then f(r,g,b) is the same linear combination of r, g and b.

From the sensor measurements for R, G, B and L, the parameters r, g and b are to be estimated. From the previous analysis, the maximum likelihood (ML) estimate for the parameters is that set of values of $\hat{r}$, $\hat{g}$ and $\hat{b}$ which maximizes:

$$-(R-\hat{r})^2/\sigma^2_r - (G-\hat{g})/\sigma^2_g - (B-\hat{b})^2/\sigma^2_b - (L-f(\hat{r},\hat{g},\hat{b}))^2/\sigma^2_L \quad (9)$$

Obviously, excluding the knowledge of L gives ML estimates of r, g, and b as the measured values R, G, B, respectively. When the L term is included, the ML estimates $\hat{r}$, $\hat{g}$, and $\hat{b}$ satisfy the equations:

$$\acute{r} = R - (\sigma^2{}_r/\sigma^2{}_L)(f(\hat{r},\hat{g},\hat{b})-L) \cdot df/dr(\hat{r},\hat{g},\hat{b}), \quad \ldots \quad (10)$$

$$\acute{g} = G - (\sigma^2{}_g/\sigma^2{}_L)(f(\hat{r},\hat{g},\hat{b})-L) \cdot df/dg(\hat{r},\hat{g},\hat{b}), \text{ and } \quad (11)$$

5

$$\hat{b} = B - (\sigma^2{}_b/\sigma^2{}_L)(f(\acute{r},\hat{g},\hat{b})-L) \cdot df/db(\acute{r},\hat{g},\hat{b}), \quad \ldots \quad (12)$$

For a general function f, equations (10),
(11) and (12) will be non-linear and will not have a
10 closed form solution. If the function f is linear in
its arguments, however, its solution can be obtained.
Thus, if it is assumed that:

$$f(r,g,b) = \alpha r + \beta g + \gamma b \quad \ldots \ldots \ldots \ldots (13)$$

15

Then, equations (10), (11) and (12), respectively,
become:

$$\hat{r} = R - (\alpha\hat{r}+\beta\acute{g}+\gamma\hat{b}-L)\alpha(\sigma^2{}_r/\sigma^2{}_L) \ldots \ldots \ldots (14)$$

20

$$\acute{g} = G - (\alpha\acute{r}+\beta\acute{g}+\gamma\acute{b}-L)\beta(\sigma^2{}_g/\sigma^2{}_L) \ldots \ldots \ldots (15)$$

$$\acute{b} = B - (\alpha\acute{r}+\beta\acute{g}+\gamma\acute{b}-L)\gamma(\sigma^2{}_b/\sigma^2{}_L) \ldots \ldots \ldots (16)$$

25 for which the solution is:

$$\hat{r} = R - (\alpha R+\beta G+\gamma B-L)\alpha(\sigma^2{}_r/\sigma^2{}_T) \ldots \ldots \ldots (17)$$
$$\hat{g} = G - (\alpha R+\beta G+\gamma B-L)\beta(\sigma^2{}_g/\sigma^2{}_T) \ldots \ldots \ldots (18)$$
$$\hat{b} = B - (\alpha R+\beta G+\gamma B-L)\gamma(\sigma^2{}_b/\sigma^2{}_T) \ldots \ldots \ldots (19)$$

30

where:

$$\sigma^2{}_T = \sigma^2{}_L + \alpha^2\sigma^2{}_r + \beta^2\sigma^2{}_g + \gamma^2\sigma^2{}_b \ldots \ldots \ldots (20)$$

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Equations (17), (18) and (19) reveal that each of the values for $\hat{r}$, $\hat{g}$ and $\hat{b}$ is simply the original measurement for its channel, corrected by a fixed fraction of the quantity $(\alpha R + \beta G + \gamma B - L)$ which is the

5   difference between the luminance signal and a luminance signal constructed from the red, green, and blue measurements.

The rms error of the estimate $\hat{r}$ is:

10     $$\sigma^2_r(1-\alpha^2\sigma^2_r/\sigma^2_T) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

which is strictly less than σ^2_r (with corresponding expressions for the error of $\hat{g}$ and $\hat{b}$, so that it can be seen that an improvement can be made in the noise

15   characteristics of the measurements.

This improvement in the noise of the red, green, and blue signals also extends to linear combinations (e.g. differentials) of these signals (such as an R-Y or B-Y signal). Generating the linear

20   combination M, directly from the measurements R, G and B as:

$$M = qR + sG + tB \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

25   yields an rms error of:

$$\sigma^2_M = q^2\sigma^2_r + s^2\sigma^2_g + t^2\sigma^2_b \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

However, if the combination is defined as:

30

$$\hat{M} = q\hat{r} + s\hat{g} + t\hat{b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

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then the rms error of the estimate becomes (after algebraic simplification):

$$\sigma^2_M = \sigma^2_M - (\alpha q \sigma^2_r + \beta s \sigma^2_g + \gamma t \sigma^2_b)^2 / \sigma^2_T \quad \ldots \ldots \ldots \quad (25)$$

5

which is always the better estimate.

In accordance with a preferred embodiment, the system will not be light-limited, so that the noise level from each sensor will be the same. The low-frequency luminance signal is obtained by averaging four luminance measurements, so that its rms noise is half that of the other channels ($\sigma_r = \sigma_g = \sigma_b = 2\sigma_L$). For exemplary parameters $\alpha = .3$, $\beta = .6$, and $\gamma = .1$, equations (17), (18) and (19) yield:

15

$$\hat{r} = R - .42A \text{ with } \sigma_{\hat{r}} = (.93)\sigma_r, \quad \ldots \ldots \ldots \ldots \quad (26)$$

$$\hat{g} = G - .85A \text{ with } \sigma_{\hat{g}} = (.70)\sigma_g, \text{ and } \quad \ldots \ldots \ldots \quad (27)$$

20 $$\hat{b} = B - .14A \text{ with } \sigma_{\hat{b}} = (.99)\sigma_b, \quad \ldots \ldots \ldots \ldots \quad (28)$$

where:

$$A = .3R + .6G + .1B = L \quad \ldots \ldots \ldots \ldots \ldots \quad (29)$$

25

By slightly modifying the coefficients to: $\alpha = .4$, $\beta = .5$, and $\gamma = .1$ the values of $\hat{r}$, $\hat{g}$ and $\hat{b}$ become:

$$\hat{r} = R - .60A \text{ with } \sigma_{\hat{r}} = (.87)\sigma_r, \quad \ldots \ldots \ldots \ldots \quad (30)$$

30 $$\hat{g} = G - .75A \text{ with } \sigma_{\hat{g}} = (.79)\sigma_g, \text{ and } \quad \ldots \ldots \ldots \quad (31)$$

$$\hat{b} = B - .15A \text{ with } \sigma_{\hat{b}} = (.99)\sigma_b, \quad \ldots \ldots \ldots \ldots \quad (32)$$

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where:

$$A = .4R + .5G + .1B - L \quad \ldots \ldots \ldots \ldots \ldots \quad (33)$$

5   The most significant reduction in noise is in the green
channel, where a 20-30% improvement in SNR can be
obtained.

The linear definition for f used here holds
only correct if the effective spectral transmittance of
10   the luminance channel is a linear combination of the
effective spectral transmittances of the red, green,
and blue channels. If this is not the case, then f is
the more complicated function given above and depends
on the spectral characteristics of the light source and
15   the film dyes; the improvement in SNR will also be
signal-dependent.

It should be recalled that the noise being
discussed here is the noise signals produced by the
sensor, i.e., measurement noise. That is, the computed
20   values are estimates of the transmittances through the
film strip 15 in the absence of measurement noise, but
any noise in the film (e.g. grain) is considered to be
part of the signal. In practice, the desired
quantities are the signals which gave rise to the film
25   record, prior to any film noise being added to the
signal. Since the measurement of blue transmittance
contains blue film noise and this measurement is now
used to compute the green and red estimates of
transmittance, there is the concern that, for example,
30   a noisy blue layer in the film will add extra noise to
the green and red estimates. However, it turns out
that this is not the case.

More particularly, with reference to the
above-described linear approximation, r, g and b
35   correspond to the respective red, green and blue film
transmittances, in the absence of both film and

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measurement noise. If the film noise (k_r, k_g, k_b) is additive in intensity space, then the measurements may be defined as:

$$R = r + k_r + n_r, \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (34)$$

$$G = g + k_g + n_g, \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (35)$$

$$B = b + k_b + n_b, \text{ and } \ldots\ldots\ldots\ldots\ldots\ldots (36)$$

$$L = \alpha(r+k_r) + \beta(g+k_g) + \gamma(b+k_b) + n_L \ldots\ldots\ldots (37)$$

If the film noise is additive in density space, the definitions are:

$$R = r10^{k_r} + n_r, \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (38)$$

$$G = g10^{k_g} + n_g, \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots (39)$$

$$B = b10^{k_b} + n_b, \text{ and } \ldots\ldots\ldots\ldots\ldots\ldots (40)$$

$$L = \alpha(r10^{k_r}) + \beta(g10^{k_g}) + \gamma(b10^{k_b}) + n_L \ldots\ldots\ldots (41)$$

In both cases the maximum likelihood estimators are unchanged from the simpler case discussed previously. Consequently, for the additive in intensity space case, the expression for $\hat{r}$ becomes:

$$\hat{r} = R-(\alpha R+\beta G+\gamma B-L)\alpha(\sigma^2_r/\sigma^2_T) \ldots\ldots\ldots\ldots (42)$$

$$= r+k_r+n_r-(\alpha n_r+\beta n_g+\gamma n_b-n_L)\alpha(\sigma^2_r/\sigma^2_T) \ldots\ldots\ldots (43)$$

Similar expressions may be derived for $\hat{g}$ and $\hat{b}$. It should be observed that contributions of k_g and k_b to $\hat{r}$ come from L as well as from G and B, but that these contributions cancel. Thus, the only increase in the rms error of $\hat{r}$ is the expected contribution from the film noise in the red layer. The same result holds for the case of noise which is additive in density space, and it also holds for linear combinations of red, green and blue signals. That is,

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$$\sigma^2_{\hat{r}} = \sigma^2_{kr} + \sigma^2_r(1 - \alpha^2\sigma^2_r/\sigma^2_T), \quad \ldots \ldots \ldots \ldots \quad (44)$$

$$\sigma^2_{\hat{g}} = \sigma^2_{kg} + \sigma^2_g(1 - \beta^2\sigma^2_g/\sigma^2_T), \quad \ldots \ldots \ldots \ldots \quad (45)$$

5

$$\sigma^2_{\hat{b}} = \sigma^2_{kb} + \sigma^2_b(1 - \gamma^2\sigma^2_b/\sigma^2_T), \quad \ldots \ldots \ldots \ldots \quad (46)$$

$$\sigma^2_M = q^2(\sigma^2_{kr} + \sigma^2_r) + s^2(\sigma^2_{kg} + \sigma^2_g) + t^2(\sigma^2_{kb} + \sigma^2_b), \quad \text{and} \quad (47)$$

$$\sigma^2_M = \sigma^2_M - (\alpha q\sigma^2_r + \beta s\sigma^2_g + \gamma t\sigma^2_b)^2/\sigma^2_T \quad \ldots \ldots \ldots \quad (48)$$

10

CONCLUSIONS

As will be appreciated from the foregoing
description, in accordance with the signal processing
mechanism of the present invention, a reduction in
15 noise is possible in a multi-band (e.g. multi-color
imagery) signal processing system by using the
information contained in a plurality of n observed
measurements $\vec{y}$ (e.g. R,G,B,L sensor outputs) related to
m intrinsic parameters $\vec{x}$ (e.g. color components) by the
20 expression $\vec{y} = \overleftrightarrow{A}\vec{x}$. The components of $\vec{y}$ are rescaled
by the measurement noise σ_i in the measurement y_i.
Letting $y_i' = y_i/\sigma_i$ and $A'_{ij} = A_{ij}\sigma_i$, so that $\vec{y}' = \overrightarrow{A}'\vec{x}$
and the measurement error in each measurement of $\vec{y}'$ is
1.0, then, given a measurement $\vec{y}'$, the best estimate of
25 the intrinsic parameters $\hat{x}$ is:

$$\hat{x} = [(A'^+A')^{-1}A'^+]\vec{y}' \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad (49)$$

The bracketed quantity in equation (49) depends only
30 upon system characteristics and the measurement noise
level. It reduces to equations (17) - (19) for the
special case described above.

Thus, in the above-described example of a
multi-color imaging processing system the low-frequency
35 luminance signal is used in combination with the red,

green, and blue signals. The actual magnitude of the
reduction depends on the relative noise levels in the
different sensors and on the details of the
relationship between the luminance signal and the three
5   color signals. (In the exemplary, but realistic case,
a reduction of green measurement noise by 20-30% can be
obtained.) If the graininess of the film is included
in the noise considerations, the proportional reduction
in noise will be smaller, but there are no
10   contributions to noise in one channel due to film noise
in another.

         While I have shown and described an
embodiment in accordance with the present invention, it
is to be understood that the same is not limited
15   thereto but is susceptible to numerous changes and
modifications as known to a person skilled in the art,
and I therefore do not wish to be limited to the
details shown and described herein but intend to cover
all such changes and modifications as are obvious to
20   one of ordinary skill in the Art.

WHAT IS CLAIMED:

      1.   For use with a multiple band image
sensor system having a plurality of first image
5   sensors, each of which produces a respective first
sensor output signal that contains an information
component representative of a respective characteristic
of said image and a noise component associated with the
operation of the sensor through which its output signal
10 is produced, and a further image sensor that produces a
further sensor output signal containing an information
component representative of a further characteristic of
said image, and which is expressible as a function of
the information components of said first sensor output
15 signals, and a noise component associated with the
operation of said further image sensor, a method of
processing said first and further sensor output signals
to reduce the noise components in said first sensor
output signals and thereby derive noise-reduced
20 estimates of each of the information components within
said first sensor output signals comprising the steps
of:
      (a)   generating a first signal,
representative of said further image sensor signal, as
25 a function of said first sensor output signals;
      (b)   generating a second signal
representative of a prescribed relationship between
said first signal and said further sensor output
signal; and
30   (c)   combining the first sensor output
signals produced by said first image sensors with said
second signal generated in step (b), to obtain said
noise-reduced estimates of the information components
of each of said first sensor output signals.

2.   A method according to claim 1, wherein
step (b) comprises generating said second signal as the
difference between said first signal and said further
sensor output signal.

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3.   A method according to claim 2, wherein
step (c) comprises subtracting a fraction of said
second signal from each of said first sensor output
signals to thereby obtain said noise-reduced estimates
10   of the information components of each of said first
sensor output signals.

4.   A method according to claim 1, wherein
step (c) includes generating a plurality of third
15   signals representative of the noise variances
associated with the operation of said first image
sensors and said further image sensor, and combining
the first sensor output signals produced by said first
image sensors with the second signal generated in step
20   (b) and said plurality of third signals, to thereby
obtain said noise-reduced estimates of the information
components of each of said first sensor output signals.

5.   A method according to claim 4, wherein a
25   respective one of said third signals is representative
of the ratio of the noise variance associated with the
operation of a respective first image sensor to a
summation of the noise variances associated with the
operation of said plurality of first image sensors and
30   said further image sensor.

6.   A method according to claim 1, wherein
said plurality of first image sensors produce first
sensor output signals associated with respectively
35   different color components of an image, and wherein
step (a) comprises generating said first signal as a

linear function of the respectively different color
representative first sensor output signals.

7.   A method according to claim 6, wherein
said further image sensor produces said further sensor
output signal in accordance with a luminance component
of said image, and wherein step (b) comprises
generating said second signal as the difference between
said first signal and said luminance component
representative further sensor output signal. '

8.   A method according to claim 1, wherein
said plurality of first image sensors produce first
sensor output signals R, G and B, respectively .
associated with red, green and blue color components of
an image, and wherein step (a) comprises generating a
first signal S1 as a linear function of the respective
red, green and blue color representative first sensor
output signals, in accordance with the relationship:
$$S1 = aR + bG + cB,$$
where a, b and c are prescribed coefficients.

9.   A method according to claim 8, wherein
said further image sensor produces a further sensor
output signal L in accordance with a luminance
component of said image, and wherein step (b) comprises
generating a second signal S2 as the difference between
said first signal S1 and said luminance component
representative further sensor output signal L.

10.   A method according to claim 9, wherein
step (c) includes generating a plurality of third
signals S3, a respective one of which is representative
of the ratio of the noise variance associated with the
operation of a respective first image sensor to a
summation of the noise variances associated with the

operation of said plurality of first image sensors and
said further image sensor, and combining the first
sensor output signals R, G and B produced by said first
image sensors with the second signal S2 generated in

5   step (b) and said plurality of third signals, to
thereby obtain said noise-reduced estimates of the
information components of each of said first sensor
output signals.

10   11.   A method according to claim 10, wherein
a respective third signal, associated with one of said
color components, is proportional to a product of a
corresponding one of said coefficients and the ratio of
the noise variance associated with the operation of a

15   respective first image sensor to a summation of the
noise variances associated with the operation of said
plurality of first image sensors and said further image
sensor.

20   12.   For use with a multiple band image
sensor system having a plurality of first image
sensors, each of which produces a respective first
sensor output signal that contains an information
component representative of a respective characteristic

25   of said image and a noise component associated with the
operation of the sensor through which its output signal
is produced, and a further image sensor that produces a
further sensor output signal containing an information
component that is representative of a further

30   characteristic of said image, and is expressible as a
function of the information components of said first
sensor output signals, and a noise component associated
with the operation of said further image sensor, a
method of processing said first and further sensor

35   output signals to reduce the noise components in said
first sensor output signals and thereby derive noise-

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reduced estimates of each of the information components
within said first sensor output signals, said method
comprising the steps of:

         (a)   generating a first signal,
5   representative of the information component within said
further image sensor signal, as a function of said
first sensor output signals;

         (b)   generating a plurality of second signals
representative of the noise variances associated with
10   the operation of said first image sensors and said
further image sensor; and

         (c)   combining the first and further sensor
output signals produced by said first and further image
sensors, respectively, with said first signal generated
15   in step (a) and said plurality of second signals
generated in step (b), to obtain said noise-reduced
estimates of the information components of each of the
information components within said first sensor output
signals.
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         13.   A method according to claim 12, wherein
a respective one of said second signals is
representative of the ratio of the noise variance
associated with the operation of a respective first
25   image sensor to a summation of the noise variances
associated with the operation of said plurality of
first image sensors and said further image sensor.

         14.   A method according to claim 13, wherein
30   said plurality of first image sensors produce first
sensor output signals associated with respectively
different color components of an image, and wherein
step (a) comprises generating said first signal as a
linear function of the respectively different color
35   representative first sensor output signals.

15. A method according to claim 14, wherein said further image sensor produces said further sensor output signal in accordance with a luminance component of said image, and wherein step (c) comprises

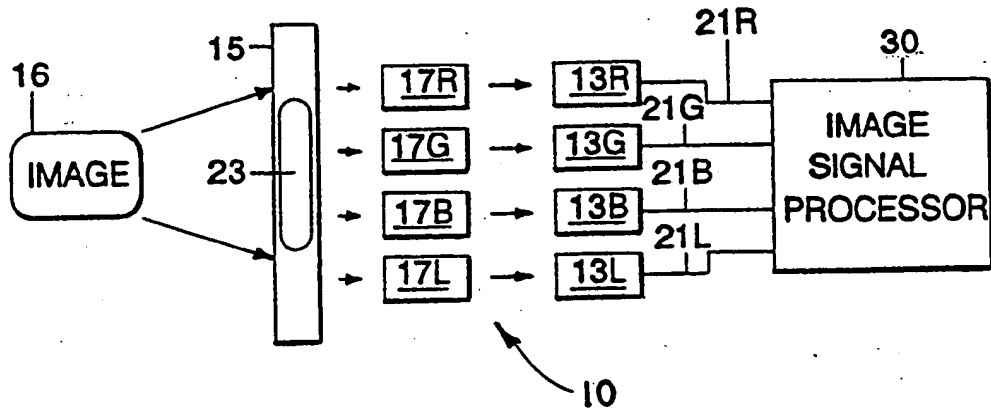5 generating a third signal as the difference between said first signal and said luminance component representative further sensor output signal and subtracting from said first sensor output signals respective combinations of said second and third

10 signals.

16. A method according to claim 15, wherein said plurality of first image sensors produce first sensor output signals R, G and B, respectively

15 associated with red, green and blue color components of an image, and wherein step (a) comprises generating a first signal S1 as a linear function of the respective red, green and blue color representative first sensor output signals, in accordance with the relationship:

20                    $S1 = aR + bG + cB,$
where a, b, and c are prescribed coefficients.

17. A method according to claim 16, wherein said further image sensor produces a further sensor

25 output signal L in accordance with a luminance component of said image, and wherein step (c) comprises generating a third signal as the difference between said first signal S1 and said luminance component representative further sensor output signal L.

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18. A method according to claim 17, wherein step (c) includes generating a plurality of second signals, a respective one of which is representative of the ratio of the noise variance associated with the

35 operation of a respective first image sensor to a summation of the noise variances associated with the

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operation of said plurality of first image sensors and
said further image sensor, and combining the first
sensor output signals R, G and B produced by said first
image sensors with said third signals and said
5   plurality of second signals, to thereby obtain said
noise-reduced estimates of the information components
of each of said first sensor output signals.

19.   A method according to claim 18, wherein
10   a respective second signal, associated with one of said
color components, is proportional to a product of a
corresponding one of said coefficients and the ratio of
the noise variance associated with the operation of a
respective first image sensor to a summation of the
15   noise variances associated with the operation of said
plurality of first image sensors and said further image
sensor.

20.   For use with a multiple color image
20   sensor system having a plurality of first image
sensors, each of which produces a respective first
sensor output signal that contains a respective color
representative component of said image and a noise
component associated with the operation of the sensor
25   through which its output signal is produced, and a
further image sensor that produces a further sensor
output signal containing a luminance representative
component of said image, and which is expressible as a
function of the color components of said first sensor
30   output signals, and a noise component associated with
the operation of said further image sensor, a method of
processing said first and further sensor output signals
to reduce the noise components in said first sensor
output signals and thereby derive noise-reduced
35   estimates of each of the color components within said
first sensor output signals comprising the steps of:

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    (a)   generating a first signal, representative of said further image sensor signal, as a function of said first sensor output signals;

    (b)   generating a second signal

5 representative of a prescribed relationship between said first signal and said further sensor output signal; and

    (c)   combining the first sensor output signals produced by said first image sensors with said

10 second signal generated in step (b), to obtain said noise-reduced estimates of the color components of each of said first sensor output signals.

    21.   A method according to claim 20, wherein

15 step (b) comprises generating said second signal as the difference between said first signal and said further sensor output signal, and wherein step (c) comprises subtracting a fraction of said second signal from each of said first sensor output signals to thereby obtain

20 said noise-reduced estimates of the color components of each of said first sensor output signals.

    22.   A method according to claim 20, wherein step (c) includes generating a plurality of third

25 signals representative of the noise variances associated with the operation of said first image sensors and said further image sensor, and combining the first sensor output signals produced by said first image sensors with the second signal generated in step

30 (b) and said plurality of third signals, to thereby obtain said noise-reduced estimates of the color components of each of said first sensor output signals.

    23.   A method according to claim 22, wherein

35 a respective one of said third signals is representative of the ratio of the noise variance

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associated with the operation of a respective first
image sensor to a summation of the noise variances
associated with the operation of said plurality of
first image sensors and said further image sensor.

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　　　　24.　A method according to claim 20, wherein
step (a) comprises generating said first signal as a
linear function of the respectively different color
representative first sensor output signals, and wherein
10　step (b) comprises generating said second signal as the
difference between said first signal and said luminance
component representative further sensor output signal.

　　　　25.　A method according to claim 20, wherein
15　said plurality of first image sensors produce first
sensor output signals R, G and B, respectively
associated with red, green and blue color components of
an image, and wherein step (a) comprises generating a
first signal S1 as a linear function of the respective
20　red, green and blue color representative first sensor
output signals, in accordance with the relationship:
$$S1 = aR + bG + cB,$$
where a, b and c are prescribed coefficients, and
wherein step (b) comprises generating a second signal
25　S2 as the difference between said first signal S1 and
said luminance component representative further sensor
output signal.

　　　　26.　A method according to claim 25, wherein
30　step (c) includes generating a plurality of third
signals S3, a respective one of which is representative
of the ratio of the noise variance associated with the
operation of a respective first image sensor to a
summation of the noise variances associated with the
35　operation of said plurality of first image sensors and
said further image sensor, and combining the first

sensor output signals R, G and B produced by said first
image sensors with the second signal S2 generated in
step (b) and said plurality of third signals, to
thereby obtain said noise-reduced estimates of the
5   color components of each of said first sensor output
signals.

27.   A method according to claim 26, wherein
a respective third signal, associated with one of said
10   color components, is proportional to a product of a
corresponding one of said coefficients and the ratio of
the noise variance associated with the operation of a
respective first image sensor to a summation of the
noise variances associated with the operation of said
15   plurality of first image sensors and said further image
sensor.

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (il several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC⁵: H 04 N 5/217, H 04 N 9/04, H 04 N 1/46

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷

Classification System	Classification Symbols
IPC⁵	H 04 N 5/00, H 04 N 9/00, H 04 L 25/00, H 04 N 1/00

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included In the Fields Searched ⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹

Category⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	GB, A, 2191061 (ROBERT BOSCH GmbH) 2 December 1987 see the whole document --	1,12,20
A	B. Widrow et al.: "Adaptive Signal Processing", 1985, Prentice-Hall, (Englewood Cliffs, US), chapters 5 and 12 see pages 71-75,302-329; figures 12.13 --	1-3,12,20-22, 24
A	IEEE Transactions on Electron Devices, vol. ED-32, no. 8, August 1985, IEEE, (New York, US), W.C. McColgin et al.: "Analysis and measurement of pattern noise in color-filter arrays for image sensors", pages 1411-1416 see the whole article --	1,4,5,12,13, 20,22,23
P,A	EP, A, 0368614 (CANON K.K.) 16 May 1990 see the whole document -----------------	1,2,6,8,12, 20,24,25

° Special categories of cited documents: ¹⁰

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
23rd April 1991	3 1. 05. 91

International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	Mme Dagmar FRANK

Form PCT/ISA/210 (second sheet) (January 1985)

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 27/05/91
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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
GB-A- 2191061	02-12-87	DE-A-	3617837	03-12-87
		JP-A-	62287788	14-12-87
EP-A- 0368614	16-05-90	JP-A-	2128591	16-05-90
		JP-A-	2142292	31-05-90
		JP-A-	2142294	31-05-90
		JP-A-	2142293	31-05-90